3D Terrain Modeling Algorithm Based on Judgment of Viewpoint Motility Factors

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Abstract
In order to improve the modeling speed and rendering effect of standard LoD (level of detail) terrain rendering algorithm in application of 3D scene reconstruction, a 3D terrain modeling algorithm is proposed based on judgment of viewpoint motility factors. First according to the sports properties of viewpoint, combined with the spatial coherence of the topographic data, the viewpoint motility factors are used to determine whether the system need to render the new terrain blocks. And the potential visual area is calculated based on Kalman filtering method. And then use square division principle to eliminate the cracks which were generating in the process of optimizing viewpoint prediction. Simulations show that compared with the standard LoD algorithm, the proposed 3D terrain modeling algorithm has the higher drawing precision and the better rendering.

Key words: LoD Terrain Rendering, 3D Reconstruction, Details Optimized, Viewpoint Prediction, Cracks Elimination, The Square Divided.

1. INTRODUCTION
With the rapid development of computer hardware computing power, in the large-scale terrain roaming system, the demand of terrain rendering efficiency is increasingly high. And the request of the large-scale terrain navigation of real-time quality and the authenticity of topography shows that people are also more and more strict (Cignoni et al., 2013). In 3D terrain visualization, terrain data volume accounted for a large proportion, it determines whether the system has a good user experience performance or not, while it as the most important basis of three-dimensional geographic system (Losasso and Hugues, 2014). In the process of terrain rendering, due to geographical information is a huge amount of data, only covers several square kilometers of terrain data model is being even more polygons. Terrain accuracy is higher, the demand for the greater the amount of data, it makes the rendering terrain data in the process of drawing and transfer with great difficulty, which becomes a more difficult to conquer in the terrain visualization system of the subject (Asirvatham and Hoppe, 2014).

3D modeling is a hot and difficult problem in the field of 3D GIS. Many scholars have done a lot of work in this field. The emphasis is on the surface of 3D solid, such as terrain, buildings, and geological aspects. The final establishment of the surface may be closed, or not be closed. Mainly include: TIN and the Grid model, boundary representation (B-rep) model, the wire frame model, cross-section model, section - triangle network hybrid model and multi-layer DEM modeling, etc. (Hu and Zhao, 2013). The modeling algorithm proposed by Requicha based on the entity is often used in the area of computer aided design, is a kind of modeling method which is similar to the actual machining process, such as cutting, drilling, etc. (Schneider and Weaterrmann, 2013). Hillyard and Braid the geometric entities as physical framework, when the first frame in Free State, the loose connections. Points and edges respectively corresponding to the framework of nodes and connecting rod, and size information are some framework is restrained and fixed the firmware (Livny et al., 2012). Molennar presents a 3D vector data structure model. The model is a simple extension of 2D topological data model. It takes 4 basic geometric elements as nodes, arcs, edges and surfaces as the basic types of graphics, and the relationship between geometric elements and object types is determined by 5 principles (Strugar, 2012). Roberts studies the “building blocks” of the world, in the preparation of computer programs from the target digital images extracted from the 3D structure of the polyhedron, and the shape of objects and their spatial relations are described, his work to create a real world for the purpose of understanding the real world of machine vision (Hu et al., 2014). Chen et al., on the basis of stereo pairs in a large-scale aviation, building 2D boundary detection by Canny operator, and then based on this, it improved adaptive least-square algorithm is applied to the pyramid matching algorithm, the effective control of the error, ultimately successful for the three-dimensional information of the building and realized on the structure of the three-dimensional modeling (Herrero and Antonio, 2013). Kuthirummal designs ring imaging system, which can be done in an image available to the
whole perspective of object image, combined with depth of field camera depth information collected, and then realize the target of 3D reconstruction (Yusov and Shevtsov, 2014).

According to the defects of the LoD terrain rendering algorithm in 3D scene reconstruction, we propose a 3D modeling algorithm based on judgment of viewpoint motility factors, and its experimental simulations show the validity of the improved strategy.

2. 3D SCENE RECONSTRUCTION ALGORITHM BASED ON THE LoD TERRAIN RENDERING

3D terrain visualization mapping is generally using DEM digital elevation model format data, which is in accordance with the rectangular grid terrain height value of the sample. Digital terrain model is to use a lot of choice the known coordinate points \(X, Y, Z\) for a simple statistical continuous surface in an arbitrary coordinate field, or other, DTM is simple digital representation of terrain surface.

Digital terrain model of a more general definition is to describe a variety of numerical array orderly information space distribution of the earth surface form, from the mathematics, it can be used an ordered set values of the following 2D function series to broadly express rich content and various forms of digital terrain model.

\[
K_p = f_i(u_p, v_p), k = 1, 2, ..., m; p = 1, 2, ..., n \quad (1)
\]

In the equation, \(K_p\) is the value of No. \(k\) ground feature information on the No. \(p\) ground point; \((u_p, v_p)\) is the 2D coordinates of No. \(p\) ground points, can be used on any map projection plane coordinates, or the latitude and longitude and matrix ranks number, etc.; \(m, m \geq 1\) is the number of the ground feature information types; \(n\) is the number of the ground points.

In the equation (1), when \(m = 1\) and \(f_i\) as the mapping of ground elevation, \((u_p, v_p)\) as matrix ranks number, the expression of digital terrain model is known as digital elevation model in equation (1). In fact, DEM is the most basic part of DTM, and it is a discrete digital expression of the earth’s surface topography.

In a word, digital elevation model is denoting to the finite sequence of 3D vector on the area, described in the form of a function is as follows.

\[
V_i = (X_i, Y_i, Z_i), i = 1, 2, ..., n \quad (2)
\]

In the equation (2), \(X_i\) and \(Y_i\) are the horizontal coordinate, and \(Z_i\) is the corresponding elevation to \((X_i, Y_i)\).

When the plane positions of each plane vector in the sequence are arranged regular grid, its plane coordinate can be omitted, DEM is simplified as a one-dimensional vector sequence.

\[
(Z, i = 1, 2, ..., n) \quad (3)
\]

In many applications, the terrain data size is larger, DEM data volume is very big also, run the moment not all data can be imported into the memory, so various terrain roaming or real-time rendering algorithms usually use depending on the relevant LoD algorithm and cuts to reduce the number of drawing, achieve the goal of real-time rendering.

Terrain LoD model usually adopt continuous level of detail (dynamic) model, this model does not generate an explicit detail level, in the process of drawing, the automatic generation and viewpoints related to the level of detail. According to the terrain rendering model, continuous LoD model can be divided into continuous LoD model based on the regular grid and the continuous LoD model based on regular grid.

Continuous level of detail algorithm based on regular grid is described as follows.

(1) Elevation function \(z(x, y, t)\), among them \(x, y, t \in R\), the parametric representation of time, distance, or scaling factor, the function is used to mix two level of detail on the same domain, makes the grid over time or distance to the point of view of continuous change.

(2) Elevation function \(z(x, y)\) in definitional domain \(R^2\), function \(z\) means in different regions with different level of detail terrain. When the discrete said the level of detail terrain grid, two adjacent terrain blocks may be due to different resolution, on the border cannot be completely aligned, along the border of the terrain block cracks may occur. If the value of the vertical height is not consistent, then the height \(z\) is discontinuous.

(3) Distribution function of polygons is \(n(v, A)\), for any given area \(A \subset R^2\), the polygon number in area corresponds to the point of view is continuous. Because the image is discrete, define a continuous equation \(a(\delta, n)\), \(n\) is continuous, if and only if there is \(\varepsilon \leq 1\) a certain, when \(\delta \to 0\), \(a(\delta, n) \to \varepsilon\) a and for small enough viewpoints of change, change in number of triangle area \(A\) up to only one, finally draw a triangle number along with the change of viewpoint is continuous.

When the GPU is not enough powerful, continuous level of detail model has been widely attention, although it sacrifices the CPU time, but due to simplify the effect is very good, provides real-time, interactive rendering of terrain scene with a possibility.
Although the resolution of the LoD algorithm has global unified, therefore, model is of good quality, and it is not easy to produce the data redundancy. However, the algorithm takes up a lot of memory, real-time computation, generate slower, poor flexibility, and easy to generate a lot of small triangle. Is not conducive to produce a better visual effect, and it is not convenient for management.

3. 3D RECONSTRUCTION MODEL BASED ON THE DETAILS OPTIMIZED LOD ALGORITHM

3.1. LoD Terrain Rendering Optimization Based on Perspective Prediction

According to the sports properties of the viewpoint, combined with the topographic data of the spatial coherence, using the viewpoint movement factor to determine whether a system need to apply colours to a drawing of new terrain block, if required, based on the Kalman filter method to calculate the potential viewing area. Memory scheduling data could be divided into \( N \) three data scheduling area as visible range \( S \), potential horizon \( P \) and unload domains \( N \). In the process of data scheduling, the scheduling area terrain block information is determined by the viewpoint of sports properties.

Visible range \( S \) is loaded in the current field of view field terrain, and four areas with dark grey in \( S \) area are the highest four terrain data under the high precision of current view. Unload the domain \( N \) is the terrain data of a frame loading on visible range \( S \), is the unload terrain area which needs uninstall on the data buffer pool.

Potential horizon \( P \) for before according to the viewpoint of movement path to predict the need to draw the data area, also it is the preload data terrain module, in the process of drawing \( S \) area preloading terrain data into memory in the area.

Through the Kalman filtering method to forecast the viewpoint motion path, according to the known previously \( N \) position coordinates viewpoint movement, and simulate the motion of the point of view, which can be used to predict the location of the point of view of the next moment.

Suppose the viewpoint do uniform motion, when \( t=t_k \) target locations are \( x_{s_k}, y_{s_k} \) and \( z_{s_k} \), the speed are \( x_{v_k}, y_{v_k} \) and \( z_{v_k} \), then the viewpoint of movement is \( X(t) \), then we get equation (4).

\[
X(t) = [x_{s_k}, y_{s_k}, z_{s_k}, x_{v_k}, y_{v_k}, z_{v_k}]^T
\]

Firstly, the motion state of viewpoints do a discretization processing, through the adoption of a linear stochastic differential equation to construct a process model, create the following recursive equations. Assumes the equations of viewpoints motion are as follows.

\[
\begin{align*}
x_{s_{k+1}} &= x_{s_k} + x_{v_k} \Delta t \\
y_{s_{k+1}} &= y_{s_k} + y_{v_k} \Delta t \\
z_{s_{k+1}} &= z_{s_k} + z_{v_k} \Delta t
\end{align*}
\]

In the equation (5), \( \Delta t \) is time interval, in actual calculation, because of the point of view as a uniform motion, the process is set to 0, noise and white noise as 0, namely, the state transition matrix is

\[
A(k \mid k-1) = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix},
\]

the equation (5) is written in matrix form as follows.

\[
\begin{align*}
\begin{bmatrix} x_{s_{k+1}} \\ y_{s_{k+1}} \\ z_{s_{k+1}} \end{bmatrix} &= \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{s_k} \\ y_{s_k} \end{bmatrix} \\
\begin{bmatrix} x_{s_{k+1}} \\ y_{s_{k+1}} \\ z_{s_{k+1}} \end{bmatrix} &= \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{s_k} \\ y_{s_k} \end{bmatrix}
\end{align*}
\]

And then to modify viewpoint motion parameters, also need to establish measurement equation, the system of the observed only a viewpoint in the coordinate system of coordinates, which has the following equation (7).
\[
\begin{align*}
\begin{bmatrix}
x_k \\
y_k \\
z_k
\end{bmatrix}
&=egin{bmatrix}
1 & 0 \\
0 & 1 \\
0 & 0
\end{bmatrix}
\begin{bmatrix}
x_{k-1} \\
y_{k-1} \\
z_{k-1}
\end{bmatrix}
+ U_k \\
\begin{bmatrix}
x_k \\
y_k \\
z_k
\end{bmatrix}
&=egin{bmatrix}
1 & 0 \\
0 & 1 \\
0 & 0
\end{bmatrix}
\begin{bmatrix}
x_{k-1} \\
y_{k-1} \\
z_{k-1}
\end{bmatrix}
+ U_k \\
\begin{bmatrix}
x_k \\
y_k \\
z_k
\end{bmatrix}
&=egin{bmatrix}
1 & 0 \\
0 & 1 \\
0 & 0
\end{bmatrix}
\begin{bmatrix}
x_{k-1} \\
y_{k-1} \\
z_{k-1}
\end{bmatrix}
+ U_k
\end{align*}
\]

(7)

\(U_k\) is observation noise, because the point of view of observation for a precise coordinates, i.e. there is no noise, so the observation error is zero, \(U_k = 0\). The observation matrix is \(H_k = 1\), system observation vector is \(Z_k = x_k\).

Set the observation time cycle as \(\Delta t = \delta \cdot \frac{1}{f}\), \(\delta\) is regulatory factor, \(f\) frame rate. Through Kalman filter algorithm to predict the movement of viewpoint the steps as follows.

1. When \(t = t_0\), suppose \(P(t | t - 1)\) is the covariance matrix of \(X(t | t - 1)\), first set the initial state of motion as \(X(0 | 0)\) to the state of the viewpoint, the initial value of covariance matrices as \(P(0 | 0)\). \(X(0 | 0)\) using three times the observed value before, calculate the speed \(x_{v_0}, y_{v_0}\) and \(z_{v_0}\), set the initial value covariance matrices as \(P(0 | 0) = \begin{bmatrix} 10 & 0 \end{bmatrix}\).

2. When \(t = t_k\), the state of the system for prediction equation is as follows.

\[
\dot{X}(k | k - 1) = A(k | k - 1)X(k - 1 | k - 1)
\]

(8)

3. When \(t = t_k\), calculate the current state of covariance prediction equation as follows.

\[
P(k | k - 1) = A(k | k - 1)P(k - 1 | k - 1)A^T(k | k - 1) + Q_k
\]

(9)

4. When \(t = t_k\), the equation of calculating filter gain coefficient matrix \(K_k\) is as follows.

\[
K_k = P(k | k - 1)H_k^T(H_k P(k | k - 1)H_k^T + R_k)^{-1}
\]

(10)

5. When \(t = t_k\), calculate the equation of optimal estimate state vector \(\hat{X}(k | k)\).

\[
\hat{X}(k | k) = \hat{X}(k | k - 1) + K_k(Z_k - H_k \hat{X}(k - 1 | k - 1))
\]

(11)

6. When \(t = t_k\), the equation of state vector covariance update \(P(k | k)\) is as follows.

\[
P(k | k) = (I - K_k H_k)P(k | k - 1)
\]

(12)

Set \(Q = [1e^{-6} 0], R = [1e^{-1} 0]\), calculated by equation (8) the coordinates of the point of view on the next prediction cycle, the viewpoint of the coordinates of the last four piece of terrain data in advance to join into memory. Cycle steps (3) to (6), update the state vector and covariance matrix of state vector, continue to the next period forecast operation.

In the process of rendering terrain data, by the level of choice is according to the viewpoint to the bounding box of the actual terrain 3d distance to decide. Then, using screen error as a resolution level evaluation criteria. The current frame is obtained by calculation error screen need hierarchical tree, recursive subdivision of the root node until the required screen space error to satisfy all the nodes. Through the terrain of vertex geometric error value \(\rho\), calculate the element error screen \(\sigma\).

\[
\sigma = \rho \left(\frac{w}{2 \tan(\theta / 2)}\right)
\]

(13)

\(w\) is the pixel height of the horizon in screen, \(\theta\) is horizontal perspective of viewpoint, \(d\) is the vertical distance of the viewpoint to terrain bounding box, \(\theta\) is horizon wide-angle. The value of \(\sigma\) is to decide whether need to draw on new terrain block data for operation or not.

### 3.2. Crack Elimination Optimization Based on Square Divided

Against the viewpoint prediction optimization also has the defect of crack, use square on a principle of dividing the optimization. Front during the first stage of division of terrain blocks is divided as the \(R \times R\) way
for the original terrain, and its criterion is based largely on line-of-sight to determine the square split, terrain blocks need to be calculated for the four side of the square a value \( \varepsilon \), as shown in equation (14).

\[
\varepsilon = \rho \cdot \frac{l}{d}
\]  

(14)

\( \rho \) is accommodation coefficient, \( l \) is the square side length, \( d \) is the sight distance of the current viewpoint from the edge of the calculation. \( \varepsilon > 1 \), a square split terrain is blocks; \( \varepsilon \leq 1 \). \( \varepsilon R_{\text{max}} \) is used to express the resolution of the computing side, which is the side of the triangle, \( R_{\text{max}} \) is the maximum resolution of the terrain blocks for predetermined triangle terrain blocks. Pay attention to \( \varepsilon R_{\text{max}} \) when using, because the resolution of the triangle terrain blocks meet a power of 2 to the power, therefore \( \varepsilon R_{\text{max}} \) cannot be used directly, it needs to be adjusted, when the number of predetermined resolution there at the same time, the measures of adjusting changes.

\[
R = \begin{cases} 
2^{-n} R_{\text{max}}, & 0 \leq \varepsilon \leq 2^{-n} \\
2^{-n+1} R_{\text{max}}, & 2^{-n+1} < \varepsilon \leq 2^{-n+1} 
\end{cases}
\]  

(15)

In the equation, \( R \) is the resolution after adjustment, \( n \) is constant, it means the number of triangles resolution terrain blocks, meaning of \( \varepsilon \) and \( R_{\text{max}} \) are always the same. According to equation (15), ensures that the resolution of the calculated according to the above formula is always power to 2.

If adjacent squares are equal in size, according to the type (14), (15) to calculate their public edge resolution are equal in size, so without any treatment, the seamless connection between the two must be; When the adjacent square size, as shown in figure 1.

![Figure 1 Crack treatment square between adjacent blocks](image)

In the figure 1, the size of left and right sides terrain block is different, BEA is their public side, the resolution of the hypothesis on the left side of the triangle BJA terrain blocks is \( R_2 \), that the resolution of the terrain blocks on the edge of the BEA is \( R_2 \) on the left. On the right side of the square were split into four terrain blocks (2 x 2) small terrain blocks, so there is only two triangle resolution. And four square on the right side, the resolution of the at least one side is higher than \( R_2 \), assuming it is CD side. In addition, assume \( l \) for edge BEA side length, \( d_{\text{far}} \) for the distance from edge to BEA, \( d_{\text{near}} \) for viewpoint of the distance from the CD, there are

\[
\frac{\rho \cdot l}{d_{\text{near}}} > 1 \Rightarrow \frac{\rho \cdot l}{l + d_{\text{near}}} > \frac{1}{2} \Rightarrow \frac{\rho \cdot l}{d_{\text{far}}} > \frac{1}{2}
\]  

(15)

By equation (15) can be found, when there is a discrepancy arises between the adjacent square terrain block size, large square at the edge of the public place of terrain blocks \( \varepsilon \) must be greater than 0.5, then the left in figure 1 at edge BEA resolution terrain blocks must take maximum resolution \( R_{\text{max}} \). And its adjacent the value \( \varepsilon \) of terrain blocks in BE and BA side, which side length shorten half size because the viewpoint to the edge of the stadia unchanged, are in the range \([1/4, 1/2]\), according to the equation (14), the resolution of the two edges is \( \frac{1}{2} R_{\text{max}} \), so the resolution of the right terrain blocks in the side BEA is \( R_{\text{max}} \), terrain blocks on both left and right at the edge of the public is the seamless connection.
4. ALGORITHM PERFORMANCE SIMULATION

In order to verify the effectiveness of the improved algorithm proposed in this paper, simulation experiments on it. First do the simulation experiments for the improved LoD algorithm computational complexity and the speed of 3D scene reconstruction, the cases in different resolution comparison results as shown in the figure below:

![Figure 2 Two kinds of terrain rendering algorithm computation contrast](image1.png)

![Figure 3 Two kinds of terrain rendering algorithms to generate time contrast](image2.png)

Seen from the figures, with the increase of resolution requirements, the improved LoD algorithm in the computation of the growth rate is far lower than LoD algorithm, and the speed of 3D scene reconstruction did not significantly lower.

And then the improved algorithm which is proposed in this paper is for the instance simulation, and it was compared with the standard algorithm, the results are as follows.

![Figure 4 3D scene modeling effect of standard LoD](image3.png)
From the simulation results, the proposed 3D modeling algorithm has the higher precision of drawing and the better rendering.

5. CONCLUSIONS

As the information technologies constantly improve today, more attract people’s attention, better adapt to the demand, and is an open platform’s pursuit of success. And a 3D virtual reality application technology to achieve this requirement, 3D technology using virtual reality to build a user immersion in the virtual space, to strengthen the degree of customer understanding of the sports venues and strengthened its item of the real environment. According to the defects of LoD terrain rendering algorithm in 3D scene reconstruction, this paper proposes a 3D reconstruction model for gymnasium based on detail optimized LoD terrain rendering algorithm, the experimental simulation results show that the proposed 3D reconstruction model has the higher precision of drawing and the better rendering.

As the simulation effect of the terrain roaming is more and more realistic, and the terrain data accuracy of the needed drawing is higher and higher, the terrain data is becoming larger and larger. When it comes to loading of terrain data beyond the computer’s computation load, loading speed of topography will drops, and rendering will be worse. According to the defects of the LoD terrain rendering algorithm in 3D scene reconstruction, we put forward a 3D terrain modeling algorithm based on judgment of viewpoint motility factors. Simulations show that the proposed 3D terrain modeling algorithm has higher mapping accuracy and rendering.

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